Technical Memorandum 6-81

MAN-PORTABILITY CONSIDERATIONS FOR AN IMPROVED MEDIUM ANTIARMOR ASSAULT WEAPON (IMAAW)

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An investigation of the portability of medium antitank weapons was conducted at the request of the US Army Infantry School for the Improved Medium Antiarmor Assault Weapon (IMAAW) program. The purpose was to review and summarize the existing data base, to complete a man-portability matrix, and to provide guidance on the weight limitations for an IMAAW. The review of the data base supported the previously stated position of the US Army Human Engineering Laboratory (USAHEL) that Dragon is at or near the weight

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limit of portability for the infantryman. Conclusions were that the IMAAW gunner should be a dedicated gunner and should carry equipment reflecting that role. The IMAAW should weigh no more than 30 pounds if it is to be carried by one infantryman. If the weight of the IMAAW exceeds 30 pounds, the weapon should be crew-served. The man-portability matrix could not be completed because it was concluded that predictions of energy expenditure should not be used to evaluate portability.

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PREFACE

We wish to thank the following people for their assistance in preparing this report:

Mr. James P. Torre, Jr., Combat Support Directorate; and Mr. Bernard M. Corona, and Mr. Rayden D. Jones, Individual Soldier and Battlefield Directorate.

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MEDIUM ANTIARMOR ASSAULT WEAPON (IMAAW)

INTRODUCTION

Background

"Infantry combat has two chief requirements--to move and to fight. A squad spends far more time moving than fighting." (56,p.1). This report addresses the requirements for movement for one type of weapon: a medium antitank weapon (MAW).

A weapon which must be carried by soldiers and which satisfies hitting and lethality requirements is ineffective if it cannot be transported or if it causes exhaustion or injury. Typical infantry requirements are for a weapon that is both light and lethal, requirements which are often mutually exclusive. Therefore, a trade-off frequently must be made between lethality and weight.

Two important questions result from this trade-off: "What is the minimum weapon lethality that is acceptable to the infantry?" and "How much equipment can the infantryman carry and still operate effectively?" In this report we attempt to answer the second question and to determine an upper bound for the weight of a MAW system which is to be carried along with a soldier's other loads. From these data we hope that systems and military analysts can estimate the lethality and acceptability of a weapon.

This investigation of MAW portability was undertaken at the request of the US Army Infantry School (USAIS), Fort Benning, Georgia. Their concern over weapon system weight and portability arose after the recent termination of industry contracts to develop a replacement for the Dragon System, the Improved Medium Antarmor Assault Weapon System (IMAAWS), because "it was doubtful that a rifle squad could carry...IMAAWS very far" (Appendix A).

IMAAWS System Specifications

The weight specification for IMAAWS has been an issue at the US Army Human Engineering Laboratory (USAHEL) since the first draft Letter of Agreement (LOA) appeared in 1977. The USAHEL position has been that a single infantryman cannot be burdened with a system as heavy as IMAAWS and that weight limits are a function of the distance the system must be transported.

In a USAHEL presentation which was given by Mr. James P. Torre, Jr. to the USAIS in 1978, the following conclusions were made:

- There should be two IMAAWS requirements: one for light infantry and one for mechanized infantry.

- Estimates of current technology indicated that a system whose weight is less than 50 pounds cannot defeat future frontal armor.

- Dragon is at, or above, the upper limit of weight for portability by light infantry. For light infantry it is clearly a crew-served weapon requiring a dedicated gunner.

- An IMAAWS which has the capability of defeating Soviet armor appears to demand the support provided by mechanized units.

An examination of the IMAAWS LOA (dated 5 February 1980) and unclassified letters (Appendix A) shows the following human engineering and human factors requirements:

1. A system as heavy as 45 pounds for one-man portage.

2. The capability to accommodate 5th to 95th percentile infantrymen in all firing positions and ensembles.

3. Human performance requirements for operation, maintenance, and training for IMAAWS which do not exceed the capabilities of potential operators.

Portage requirements, either in terms of distances or scenarios, are not stated in the LOA. Neither is there an explicit requirement that 5th to 95th percentile be able to carry the system or that carrying it be within the limits of human performance. Portability, however, is addressed to some degree in the technical development plan. The US Army Materiel Development and Readiness Command (DARCOM) is expected to examine man-portability and "determine if weapon system design characteristics, coupled with human capabilities, will achieve required performance."

PURPOSE

The purpose of this investigation was to review and summarize the data base on portability that is relevant to IMAAWS in order to determine the maximum weight for this infantry system and to make recommendations pertaining to portability issues raised by the USAIS.

METHOD AND PROCEDURE

Reports of portability studies conducted by the USAHEL, other Government agencies, and private research groups were reviewed. These studies included both laboratory and field experiments. An attempt was made to relate the findings of the studies to a weapon similar to the IMAAWS. We examined the relationships among weight, portage pace, carrying distance, energy expenditure, and gunner performance after carrying the weapon system.

The investigation is divided into two parts. The first part examines issues related to the method of carry, portage distance, and implications for squad maneuvering. This section also discusses results of field portability studies of Dragon and loads and configurations similar to Dragon. The second part examines a predictive model of energy expenditure during portage in order to fill in a man-portability matrix for the USAIS.

RESULTS AND DISCUSSION

PART I

Portage Capability Required of IMAAWS Gunners

The first questions we addressed were: "What portability capabilities are required for the IMAAWS gunner?"; "How far and often will IMAAWS be carried?"; and "Is the gunner required to negotiate the same obstacles a rifleman might encounter?"

Discussions with personnel at USAIS indicate that Dragon, the currently fielded MAW, is an essential part of the rifle squad and will be transported on foot multiple short distances and for road marches as far as 10 kilometers. In these moves the Dragon gunner will accompany riflemen and machine gunners.

Military publications support these views and add the additional information cited below on the requirements for man-transportability of Dragon:

1. Dragon Medium Antitank Assault Weapon System M47, TC 23-24, August 1974. (55)

a. Paragraph 9-10. The Dragon gunner may have to displace frequently from firing position to firing position in the attack and in retrograde and from primary to alternate and supplementary positions in the defense.

b. Paragraph 9-17b. In the attack, normally at least one Dragon per platoon should accompany the maneuver element and will displace by bounds to assure continuous overwatch of the advance (Figure 1).

c. Paragraph 9-26e. In delaying actions, when maximum delay has been achieved, Dragons are withdrawn with their squad for movement to the new delay position (Figure 2).

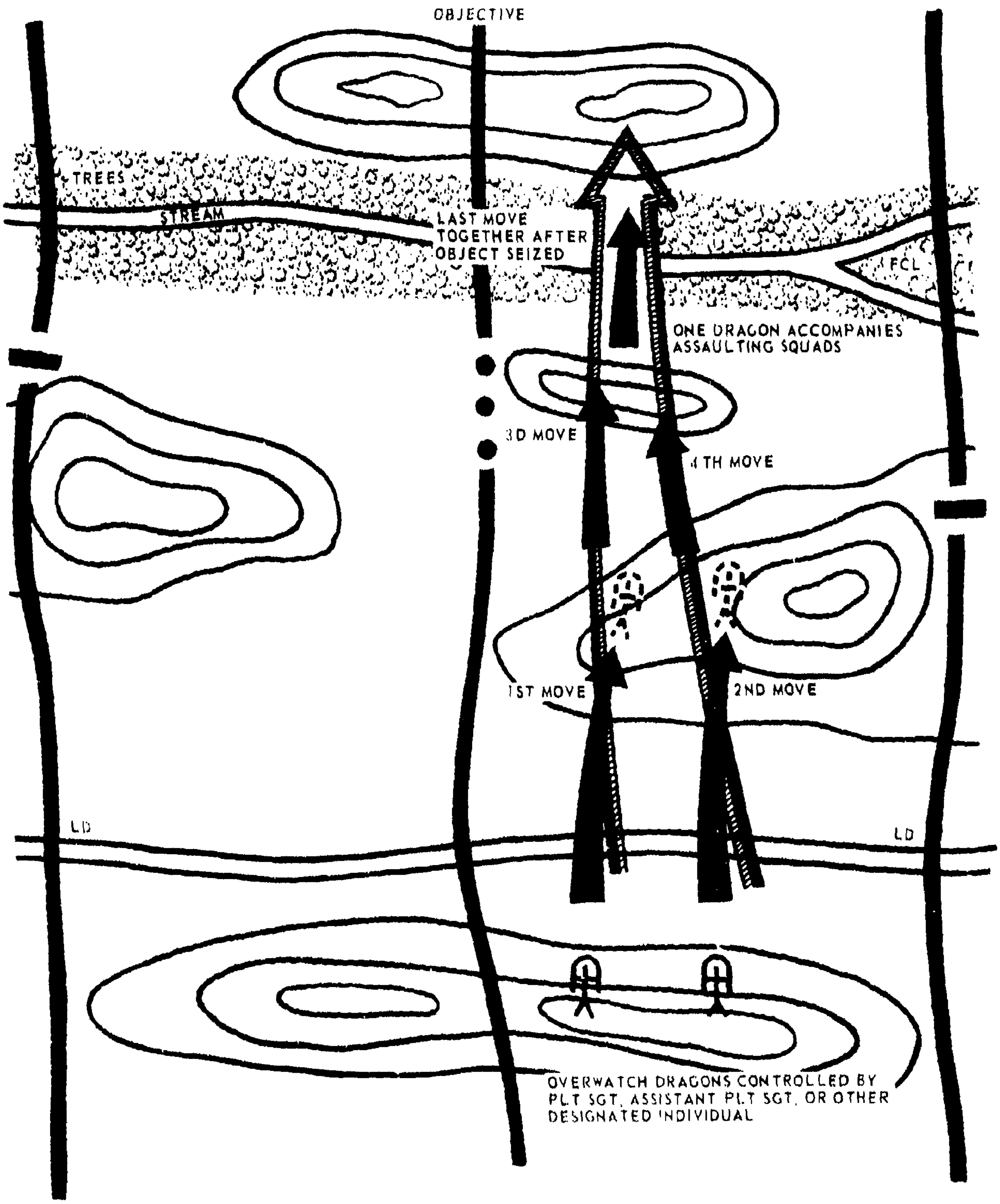


Figure 1. Dragon movements by bounds.

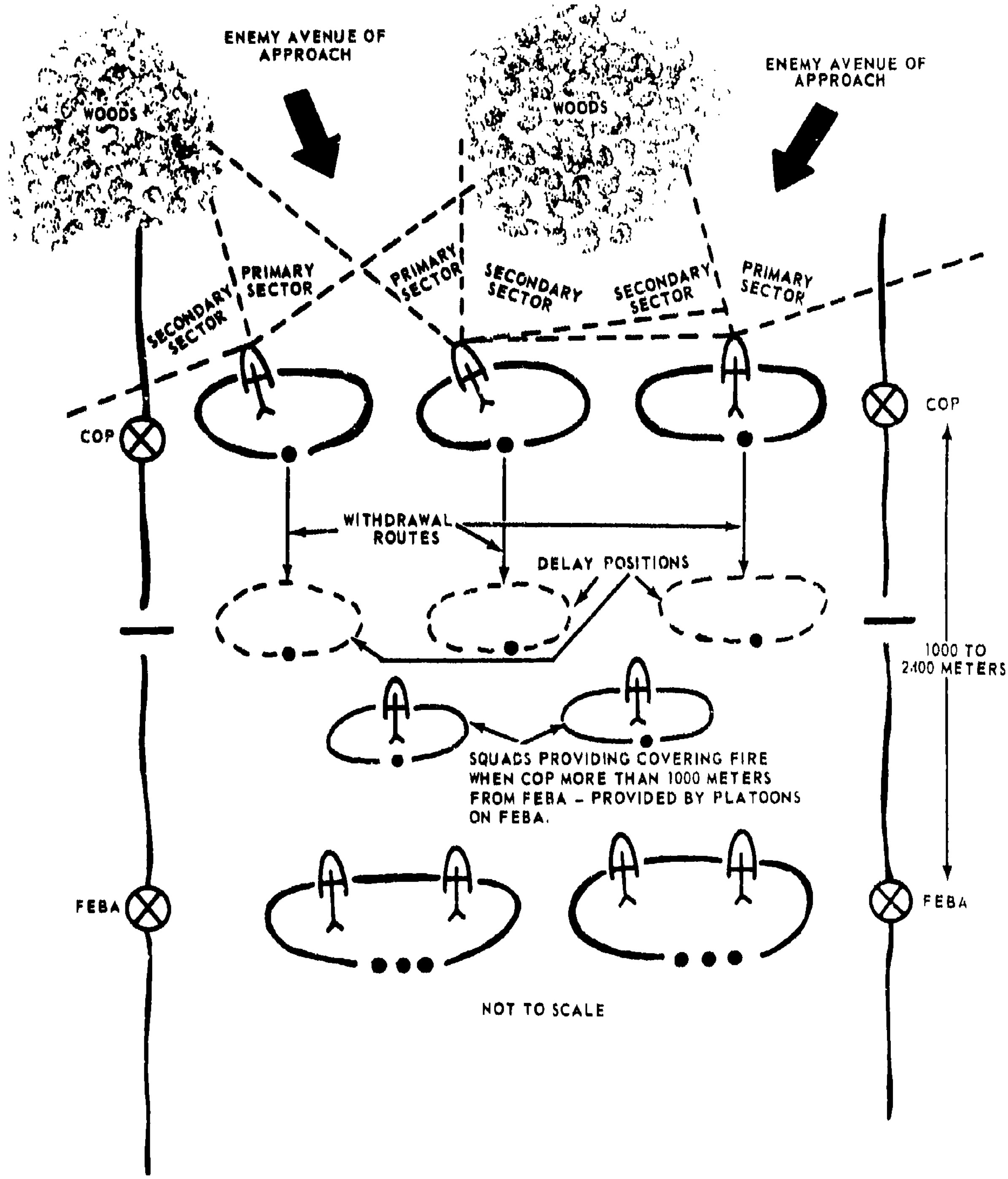


Figure 2. Dragon in the withdrawal.

d. Paragraph 9-4. The Dragon tracker and missile are designed to be used by one man. Due to the bulk of Dragon missiles, it may be necessary to form a Dragon team with one or more additional riflemen to carry ammunition, to observe targets, and to provide local security.

2. The Rifle Squad, TC 7-1 Test Edition, 1974. (56)

a. When using a bounding overwatch, a bound is normally 100 to 150 meters.

b. With travelling overwatch, the squad leader normally stays with the trailing team and keeps any attached weapons (Dragon and M60) near himself and under his direct control.

3. The Rifle Squad (Mechanized and Light Infantry) TC 7-1, December 1976. (57)

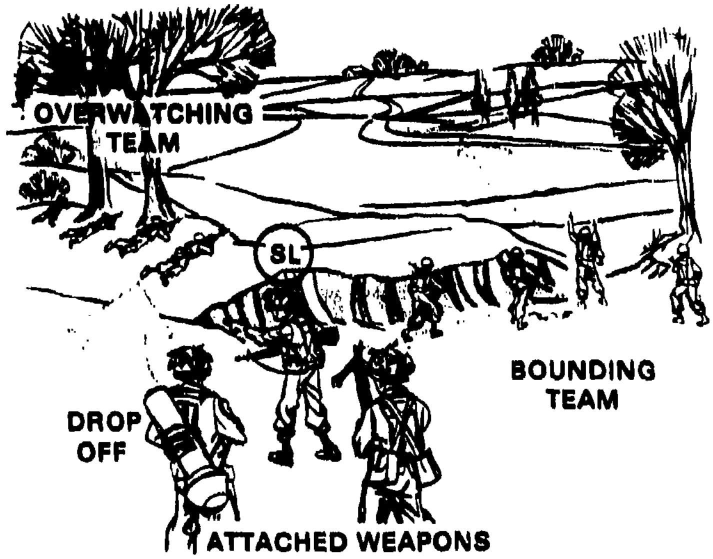
a. Figure 3 shows attached weapons, Dragon and M60, carried to an overwatch position in a bounding overwatch maneuver.

b. The maneuver team in mechanized infantry has six men with an attached M60 and an attached Dragon (Figure 4).

c. In an armor ambush there are two teams: a support/security team and an armor killer team (Figure 5).

All of the above information can be reduced to a single statement: Dragon and IMAAWS are squad weapons. An IMAAWS gunner must be able to keep up with the rest of the squad and negotiate the same distances and obstacles encountered by other squad members: rifleman or automatic weapon gunners.

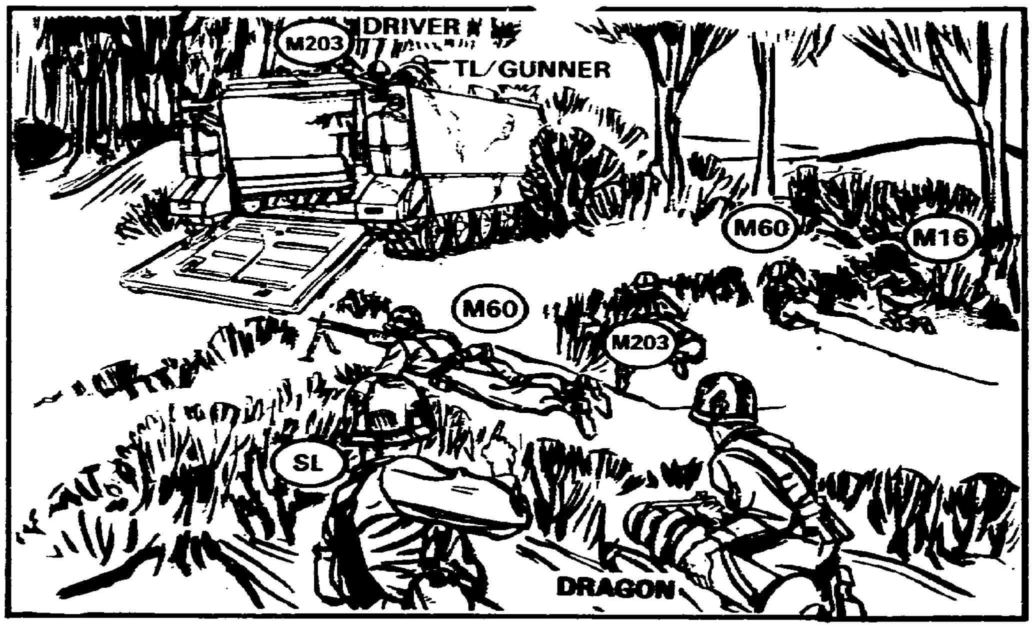
For light infantry portage, distances can be as far as 10 kilometer. For mechanized and motorized infantry, portage distances should be much less; possibly a few hundred meters. Therefore, IMAAWS portability requirements for mechanized and motorized infantry are less stringent than they are for light infantry.



During movement by bounding overwatch, the squad leader must be where he can best control his squad. He may change his location from one fire team to another. He normally will join the overwatching fire team as the bounding team passes it. In so doing, he normally takes any attached weapons with him. When with a bounding team, the squad leader moves in a position which will not mask its fire, interfere with its movement, or cause its men to shift position as he joins or leaves the team. He normally locates himself to the rear and on a flank which facilitates his drop-off to the fire team being passed. The squad leader must issue clear, concise orders. **(For orders, see appendix C.)**

Figure 3. Movement of attached weapon.

"DISMOUNT RIGHT!"



Enemy fire from the other side could have forced the squad to dismount left.

- **Dismount Right (Left).** The command is **"Dismount Right (Left)!"** As the maneuver team comes out of the carrier, they all go to the same side.

In this situation, enemy fire is directed at the carrier from the left front. The driver was able to quickly move into a covered position but was unable to face the carrier toward the enemy position. Because the enemy fire on the left side of the carrier is heavy and there is little cover to that side, the squad leader wants the entire maneuver team to get off the carrier and move to the right side. The carrier team is composed of the TL/gunner, driver, and a grenadier. The maneuver team has six men, an attached M60, and an attached Dragon.

Figure 4. Mechanized infantry maneuver team.

WITHDRAWAL TO THE OBJECTIVE RALLY POINT

The objective rally point is located far enough from the ambush site that it will not be overrun if the target attacks the ambush. Routes of withdrawal to the objective rally point are reconnoitered. Situation permitting, each man walks the route he is to use and picks out checkpoints. When the ambush is to be executed at night, each man must be able to follow his route in the dark.

On signal, the patrol quickly but quietly withdraws to the objective rally point, reorganizes, and begins its return march.

If the ambush was not successful and the patrol is pursued, withdrawal may be by bounds. The last group may arm mines, previously placed along the withdrawal route, to further delay pursuit.

The basic techniques for executing a point ambush apply equally against dismounted or armored enemy forces. When the ambush is conducted against armored forces, the far ambush is normally employed.

ARMOR AMBUSH

The purpose of an armor ambush is to destroy one (sometimes two) armored vehicles. The Dragon is normally the major armor destroying weapon used in a squad-size armor ambush. If the terrain is so thick that fields of fire are very short and armor movement is very restricted, LAWs may be the primary weapon.

This section addresses the squad as the normal size unit for an armor ambush. Given that mission, make sure each team can communicate and knows where to go, what to do, and how to get back.

To be successful, the squad leader must:

ORGANIZE

When told to conduct an armor ambush, the squad leader organizes his men, weapons, and equipment to accomplish the mission.

- Light Infantry (9-man squad, M60 MG, and Dragon attached).

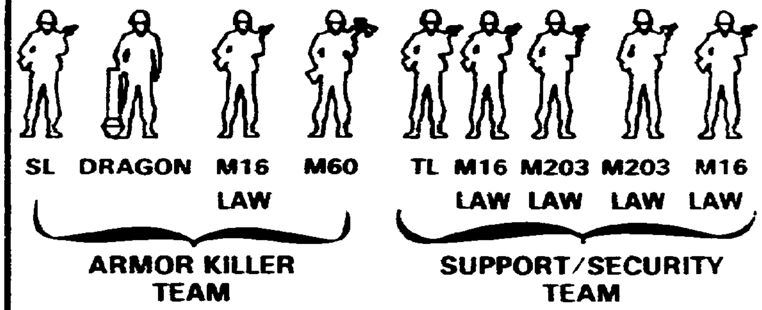


Figure 5. Armor ambush team.

Portability Issues for a Squad Automatic Weapon as They Relate to IMMAWS

A MAW, as part of an infantry squad, must be carried at the same pace as the squad's weapons. These automatic weapons include the M16AR which is the light infantry squad automatic weapon and the M60 which is often attached to a squad and colocated with the MAW; especially in an overwatching position.

The loads carried by the Dragon gunner and the M60 gunner are similar in weight. A fully loaded Dragon gunner carries about 75 pounds, 25.3 pounds of which is the round. The M60 gunner carries about 69 pounds, 23 pounds of which is the machine gun. The M60 is considered easier to carry because it has less bulk and also has a carrying handle which the gunner can use to lift the weapon during portage to relieve the strain on his shoulder.

Even though the M60 may be more portable than Dragon, it is not as portable as one might desire. That lack of portability appears to be one reason for the development of a new Squad Automatic Weapon System (SAWS) to replace the M60. The Materiel Need (MN) document for SAWS (58) states that "the M60...depletes the maneuver strength of the squad,...increases the weight squad members carry while dismounted, and decreases the ability of the squad to maneuver."

Acceptance of the premise that the M60 gunner carries too much weight should lead to a similar premise regarding the Dragon gunner. However, just the opposite result has occurred. A new machine gun lighter than the M60 is being developed, whereas the planned MAW is heavier than Dragon.

Summary of Field Experiments Regarding the Portability of Systems with IMAAWS Weight or Configuration

Seven field studies are summarized below which measured the portability of systems whose weights and configurations are similar to those proposed for the IMAAWS. Most of these studies examined portability over a test course which included a road march, cross-country march, and obstacles. Four of the studies used a test course developed by the USAHEL and one study used a test course whose design was based on the USAHEL's course.

The USAHEL test course was developed originally to examine the effect of weight and length on the portability of a light antitank weapon. Secondary purposes of the course were to examine possible system incompatibility and ruggedness during field portage. The obstacles were designed to present the subject with a number of "infantry-relevant tasks" such as running, jumping, swinging, balancing, vaulting, and crawling" (47). The cross-country and road march portions of the course were designed to fatigue subjects and acclimate them to the load they carried. The test course has been used subsequently to evaluate the portability and compatibility of other types of weapons and a wide assortment of personal combat equipment.

1. The Effects of Weight and Length on the Portability of Antitank Systems for the Infantryman, USAHEL TM 20-73 (47).

Relative portability as a function of length and weight of a light antitank system was examined. Subjects carried weapon prototypes over a 1.5 km cross-country course, a 1.4 km road-march, and then through a 700 m obstacle course. The basic load carried was 36.7 pounds, not including the weight of an 81mm diameter antitank system which was varied from 5 pounds to 24 pounds. All the test systems were carried slung over the gunner's shoulder.

Two important relationships regarding load weight that were shown in the report were the percentage of soldiers unable to keep up with the slowest man at fighting load (Figure 6) and the percent change in course time (Figure 7). The curves in these figures predict that even an antitank system with a smaller diameter and shorter length than Dragon will severely hamper portability. A questionnaire indicated that test soldiers were reluctant to carry a 24-pound system. With a 30-pound system (extrapolated from the figures), almost 85% of the soldiers would be unable to keep up with the slowest soldier without an antitank system and their obstacle course times would increase by about 50 percent.

Data on aiming accuracy after portage showed a 10-percent performance degradation from pre-portage values, but did not show any relationship between load and aiming error.

2. Portability Trial of Mock-up Round for 1980's Crew Portable Guided Antitank Weapon, APRE Report #26175 (59).

Soldiers carried through an obstacle course a fighting load of 46.8 pounds and a mock-up MAW of about 30 pounds. The addition of the antitank weapon increased the soldiers' average portage times by over 60 percent. The experimenters stated that very few men carrying the MAW would be able to keep up with their companions carrying only the fighting load. The results supported the finding in the USAHEL study discussed previously (47).

The experiment provided no data on road march times or soldiers' weapon performance after portage.

3. Human Engineering Assessment of the Infiltrator Vest Combat System VII (IVCS), USAHEL TM 3-77 (34).

The best comparison among types of loads, load weight, and load configuration is provided by this USAHEL investigation of load carrying equipment. In this experiment, soldiers carried a common load of about 40 pounds plus the load configurations for rifleman, grenadier, machine gunner, assistant machine gunner, Dragon gunner, or radio telephone operator (RTO).

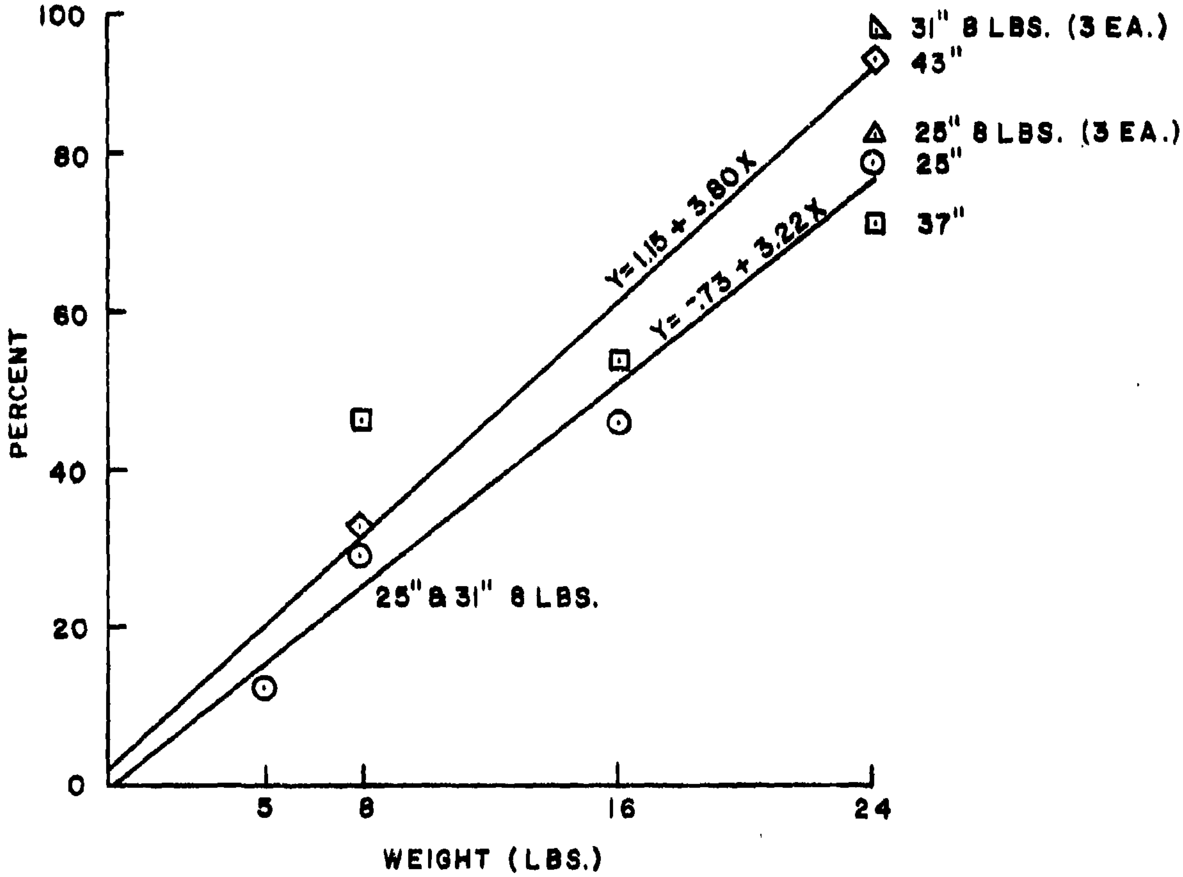


Figure 6. Percentage of men unable to keep up with slowest soldier at fighting load who is not carrying an antitank weapon.

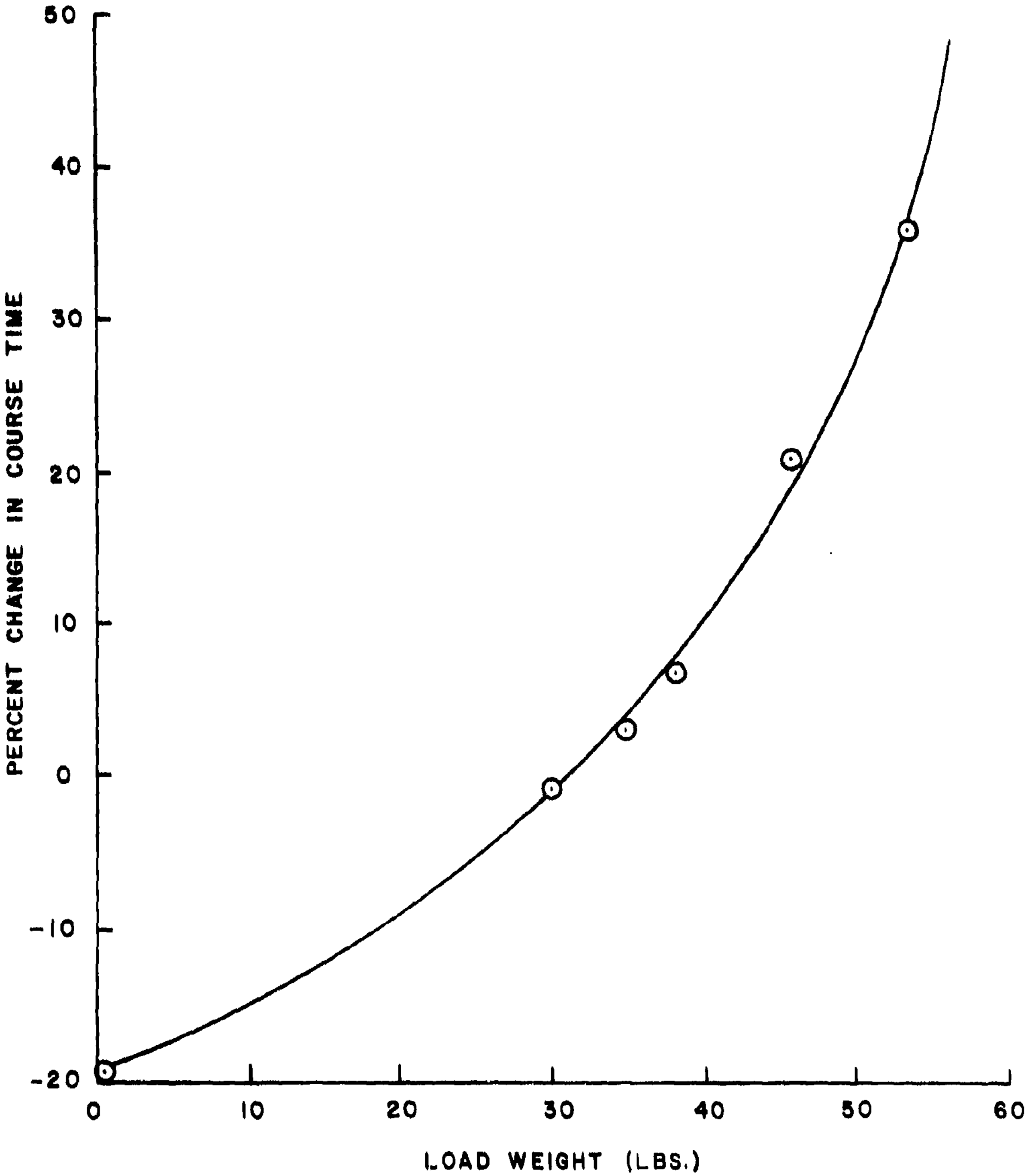


Figure 7. Percent change in course time (compared to fighting load of 32 lbs) versus load weight.

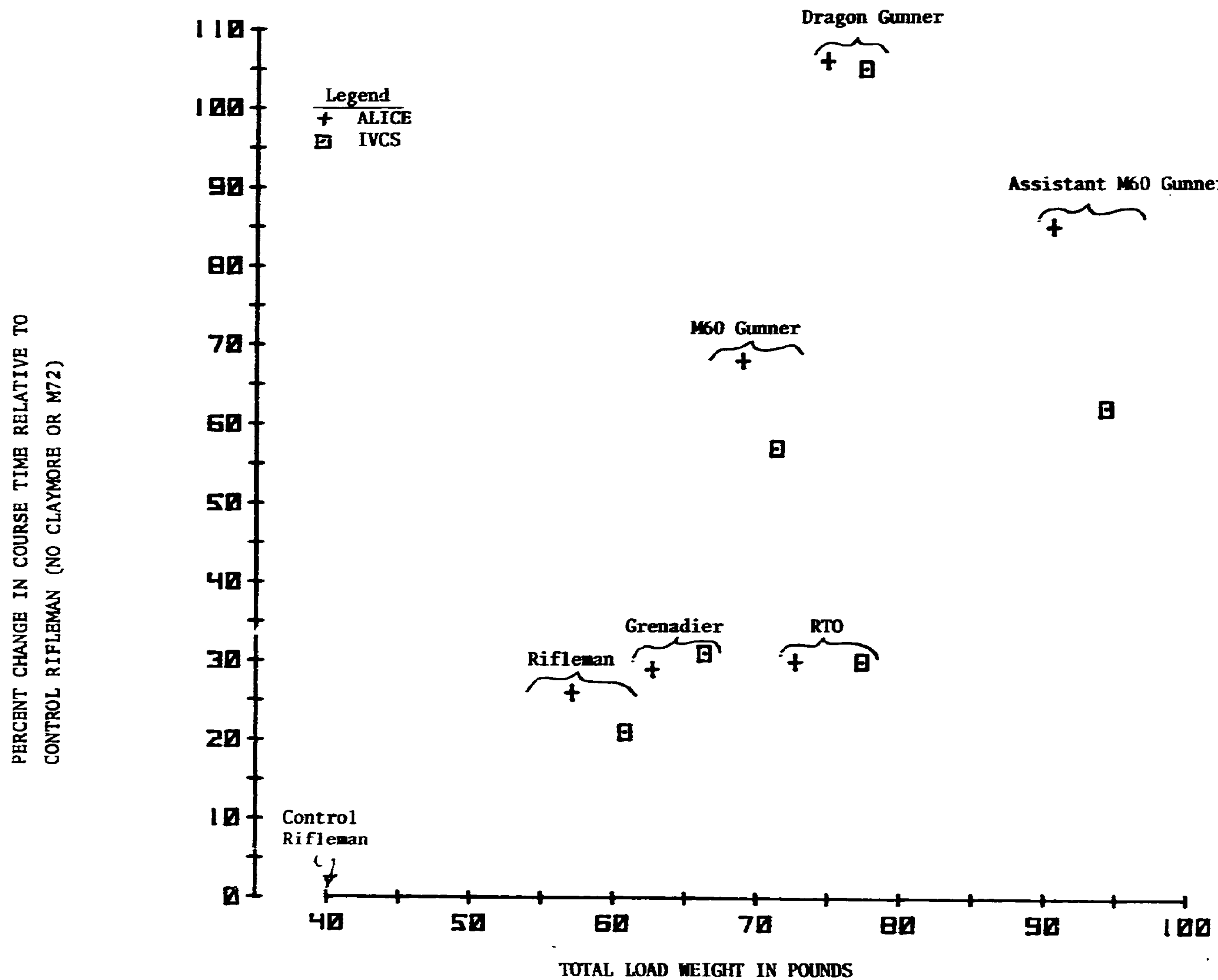


Figure 8. Load versus portage time, from HEL TM 3-77.

The Dragon gunner carried 28 pounds more than the control rifleman (75 pounds versus 47 pounds), and the Dragon gunners' obstacle course times were 85 percent slower than the riflemen's times. This result tends to support that of the previous two studies--the addition of a MAW to a basic load slows soldiers considerably.

The most interesting results of the experiment are the effects on portability of load configuration and method of carry. Figure 8 portrays graphically the relative portage times of various load configurations measured in the experiment. The most dramatic difference shown is between the Dragon gunner and the RTO, both of whom carry similar weights. The course times for the Dragon gunners were 80 percent higher.

The RTO carries a well configured load (the box shaped PRC-77 radio) in the most efficient manner: on his back. The Dragon gunner carries a heavy, thick tube by a shoulder strap, without even a handle on the weapon which he can grasp to remove some of the weight from his shoulders.

4. TOW Squad Member Loads, USAHEL Letter dated 2 August 1977 (25).

In a pilot study of TOW squad member loads, total load weight was varied from 94 pounds to 126 pounds. Test soldiers were able to complete a 3.8 km cross-country course with all loads in 80 to 90 minutes, but this length of time was 225 percent greater than the time taken by fully-loaded riflemen carrying about 40 pounds. The subjects could not negotiate the obstacle portion of the test course because the loads were unstable and too heavy. The loads could not be pulled up over obstacles and there was a high potential for blunt-trauma injuries.

5. Comparison Test of Standard ALICE and Other Back Pack System's Portability, Draft USAHEL Report (19)

In a field study of back-pack carrying systems, the infantry loads weighed 50, 90, 115, and 135 pounds. Fifty pounds of each load were comprised of the basic fighting load plus the particular load carrying system. The remaining weight, if any, consisted of steel shot molded into a foam shell which filled the interior of the pack. These loads represented optimal back-pack loads in terms of stability and center of gravity.

These loads were to have been carried twice a day over a 10 km road and cross-country course. As a result of a pilot study, though, the course was shortened to 5 km and the 135-pound load was dropped altogether. Both of the former conditions were considered "untenable" and "debilitating."

The 50, 90, and 115 pound loads were all carried around the 5 km course, but only the 50 and 90 pound loads were carried through the obstacle course. The pilot study had demonstrated that negotiation of the obstacle course with the 115-pound load "would be not only debilitating, but dangerous." Instead, after completing the 5 km course, subjects removed the pack load of 65 pounds and ran through the obstacle course with the 50-pound fighting load. The performance times from this condition were compared to those times which followed the 5 km march with the 50 pound fighting load to investigate the effects on subsequent motor performance of marching with different load weights.

No times were taken for the 5 km march. Obstacle course times, with the subjects wearing the fighting load only, were found to be unaffected by the weight of the load previously carried on the 5 km march. However, the obstacle course times for the 90-pound condition ranged from 57 to 84 percent greater than those for the fighting load. These increases in course times are less than those recorded in other studies for a Dragon gunner carrying a few pounds less, probably because of differences in load configuration and method of carry.

One important result of this experiment is that it established an upper weight limit for a balanced, well-configured load: soldiers could maneuver with a load of 90 pounds, but not maneuver with 115 pounds without risk of injury.

6. Medium Antitank Weapon Portability, Draft USAHEL Report (54).

This study measured MAW portability over short distances and tracking error after portage. Subjects carried individual or stretcher loads over a hilly dirt road for 150, 300, and 600 meters. The load weights ranged from 43 to 75 pounds for individual loads and from 110 to 144 pounds for stretcher loads in addition to about 40 pounds of basic combat gear. One minute after portage, the subjects tracked a moving target with a bipod-mounted weapon (Dragon) or a viscously damped, tripod-mounted weapon (TOW).

The relationship between load weight and increase in course time was approximately linear over the range of loads. Load configuration for individual carries did not appear to affect portage times. However, for the heaviest back-packed load (75 pounds), the subjects were unable to don or remove th' pack without assistance. Donning and removal were not a problem with test loads with shoulder straps.

Tracking performance degraded substantially after portage (Table 1). The degradation was greater for the Dragon than for the TOW and increased with the distance that the load had been carried. There was no significant difference among loads.

TABLE 1

Dragon and TOW Tracking Errors Before and After Portage
Tracking Errors (mils SD)

	Tracking Device	Rested (0 m)	After 150 m	After 300 m
Azimuth	Dragon	1.45	2.29	2.53
	TOW	0.31	0.55	0.48
Elevation	Dragon	0.89	1.64	1.86
	TOW	0.13	0.25	0.16

7. USAHEL Forward Observer Transportability Test, USAHEL TM 4-78 (9).

This experiment examined the relative portability of equipment over a hilly, 1 kilometer, unimproved dirt road. The equipment that was tested included various configurations of laser designators, mounts, and ancillary equipment for forward observers. The equipment was carried both on the back and over the shoulder. Portability times in seconds, compared to those of a soldier carrying a basic assault load, are shown in Figure 9. There were relatively small changes on this road course in portability times as a function of weight compared to the changes in obstacle course times measured in previously cited experiments.

Obstacle Courses Versus Road March Courses

It is evident that obstacle courses are more efficient discriminators among loads than open-field courses when the results of the last two experiments are compared with the results of the first five experiments. Changes in weight within a given type of load configuration and method of carry cause larger changes in relative course times for obstacle courses than for road marches. The largest difference between the two types of courses is in the relative changes in course times among load configurations and methods of carry. For road marches, the differences in relative course times depends more on weight than on configuration or method of carry. For obstacle courses, configuration and method of carry have the greater effect.

Although one type of course is a better discriminator among loads than the other, there is a question about which course is more representative of the portability requirements for a MAW. For mechanized or motorized infantry where portage distances are relatively short, a road march would be more representative of portability requirements than the obstacle course. For foot soldiers, the incidence of occurrence for obstacles would be less frequent than extended marches in an open-field, but obstacles would be encountered which would have to be negotiated. So, for the foot soldier, both types of portability courses are relevant for evaluating portability.

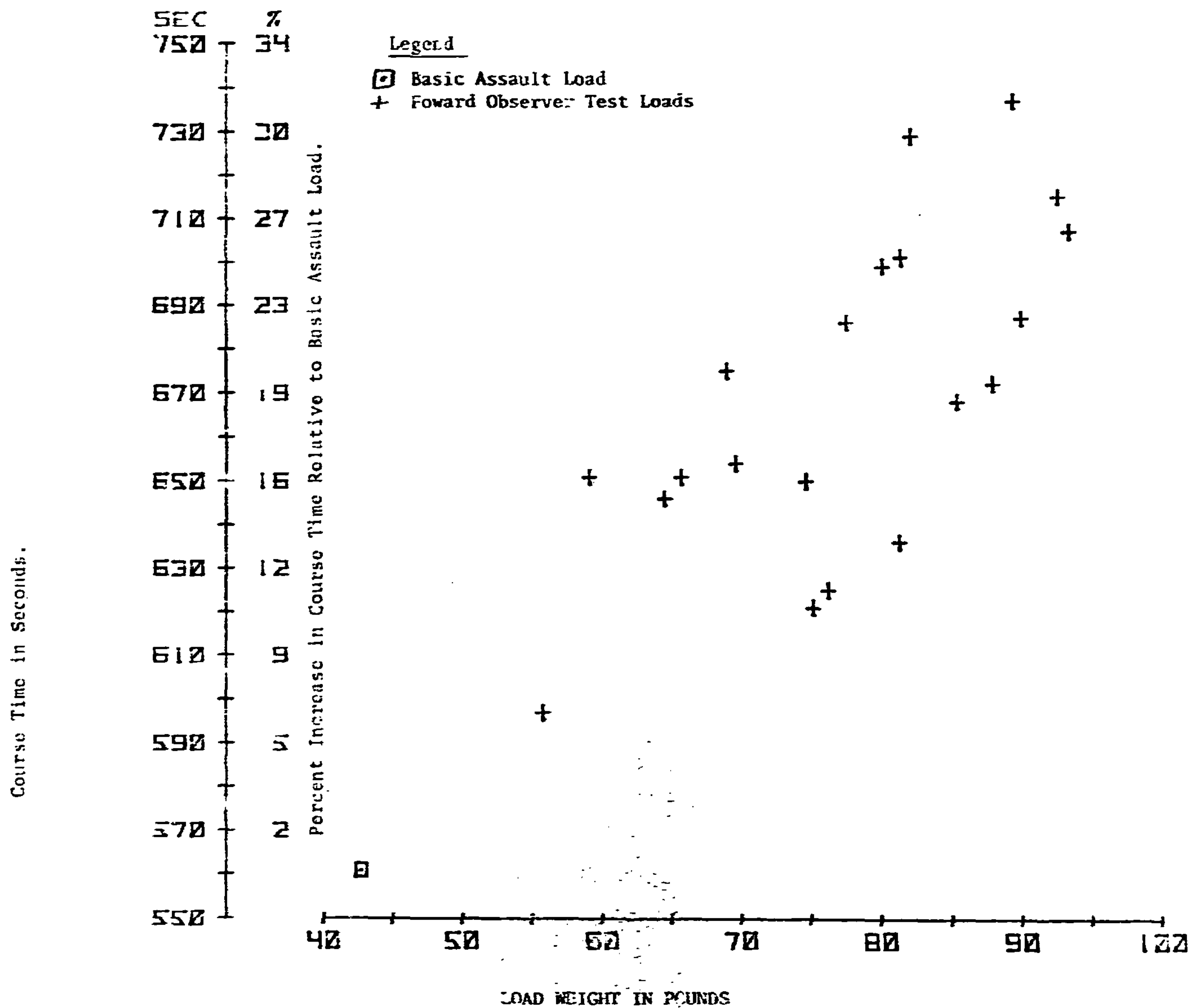


Figure 9. Load versus course time, from HEL TM 4-78.

Aiming and Tracking Performance After Portage

We have little data on performance after portage as a function of recovery time. One study (54) that measured tracking 1 minute after short distance carries (150 meters and 300 meters) showed significant degradation after portage. Although tracking after an extended recovery time was not measured, about 5 minutes after carrying the test loads the subjects appeared to have recovered because they were breathing regularly. Another study (9) which measured aiming error after negotiating an obstacle course showed similar tracking degradation for times up to 5 minutes after portage. In both studies, no significant relationship was measured between load weight and subsequent aiming or tracking error.

From this small sample of studies, we are inclined to believe that for short high energy maneuvers subsequent aiming and tracking performances will be degraded for up to 5 minutes. This degradation would appear to be related to a gunner's breathing rate and its affect on the ability to maintain a steady aim at a target. For a self-paced road march over an extended period of time, aiming and tracking performance after portage would be related to the portage pace which varies inversely with load.

Methods of Carry for IMAAWS

A review of the literature shows that heavy loads are more easily carried on the back than on the shoulder or in the hands. Although it would be desirable to carry a MAW system on the back, this cannot easily be done. First, the system will be too long. If strapped horizontally across the back, it would project too far from the gunner and present a hazard to others as well as becoming a major obstacle to maneuvering in close quarters. It could not be attached vertically to the back because it would tend to hit the soldier on the head and on the buttocks. Second, it would take too long for the soldier to remove the weapon and fire; moreover, he would probably need help in performing these tasks.

Although it is not desirable in terms of efficient portage, the IMAAWS should be carried by a strap over the shoulder. This type of carry is essential for short, rapid moves like bounding overwatches, and in moving from primary to alternate defensive positions. In these types of movements, the shoulder carry is better than back-packing because the weapon can be readied much more quickly. For these types of moves, the IMAAWS sight would most likely be attached to the tube.

In addition to a strap, the weapon should have a carrying handle to aid the gunner in removing some of the weight from the shoulder in a road march and to stabilize the weapon when transporting it rapidly for short distances.

PART II

IMAAWS Portability Matrix

We were requested by USAIS to fill in the portability matrix entitled "Suitability for 1 Man-portability" (Appendix A). This matrix specified values for several variables affecting portability. Since no previously conducted studies have investigated portability using the weights, times, or percentiles suggested by USAIS, and even small changes in the values can have great effects on portability, we attempted to predict portability by estimating the metabolic cost, in watts, of carrying loads under each of the conditions specified by the USAIS. The formula used to estimate these costs (11,33) was derived from and verified by both field and treadmill studies. We are confident that, within limits, this formula provides a good estimate of energy expenditure. Whether energy expenditure is well-correlated with portability is a matter which will be discussed.

Little is known of the relationship between portability data from treadmill studies and the data from field studies. At least one study (55) claims that the body movements involved in walking on a treadmill differ from those used in road marching and result in a 10% increase in energy expenditure. Contradicting this result is a study by Soule and Goldman (41) in which no difference was found between the actual metabolic cost of walking on blacktop and the predicted cost from treadmill data. The authors were surprised by this result and extended their study to include a direct comparison between blacktop and treadmill load carrying. The results again showed no difference.

Since studies of metabolic cost (treadmill studies) and of portage time (field studies) have both proved to be relatively insensitive to small changes in load design, it is to be expected that the results of these two types of studies might disagree. Such was the case reported by McGinnis (28) when treadmill data indicated that one load-carrying system was superior to others while field data suggested just the opposite. This sort of contradiction should not be taken as an indication of a fundamental difference between field and treadmill studies; rather, the disagreement highlights the inability of either type of study to detect reliably any performance differences because of load design.

Before we attempt to provide some answers to the question of IMAAWS man-portability, we should point out some of the shortcomings of this sort of yes-no matrix for portability. After delineating some of the general problems that permeate portability research, we will discuss specific problems associated with each of the variables that compose the matrix. We will also estimate the metabolic costs associated with man-portage of a weapons system under the conditions imposed within each cell of the matrix. These metabolic costs will be shown to be imperfect indicators of the portability of a weapon system.

General Problems

The matrix for man-portability is an oversimplified view of what is involved in the carrying of loads. Over the years that load-carrying behavior has been studied, a bewildering number of variables affecting portage have been discovered. The matrix makes use of only five of these variables:

1. Load weight.

2. Portage speed.

3. Portage distance.

4. Personnel percentile (presumably body weight).

5. Engagement condition (post-portage task).

The remaining variables can be divided into four general classes:

	References
1. Load variables	
Method of carry	(7,15,16,33,40,47)
Location with respect to the soldier's center-of-gravity	(5,33,43)
Freedom of movement allowed	(5,13)
Bulk	(47)
Design characteristics of the load	(2,8,28,52)
Number of separate components	(47)
2. Task variables	
Type of equipment (as defines the task)	(12)
Terrain type	(1,10,13,14,15,41,47)
Terrain slope	(1,10,36)
Climate	(47)
Who will do the carrying	(12,47)

	References
Type of activity (e.g., march, assault, or patrol)	(12)
Duration	(12,47)
Number of repetitions	(42,47)
Opportunity for rest	(21,27,42)
3. Soldier variables, physical	
Sex	(1,10)
Height	(14)
Strength	(1,4)
Tolerance of musculature and skeleton to loads	(5,40)
Basal metabolism	(1,46)
Aerobic power	(10,46)
Pacing ability	(4)
Training	(27,30)
Stride length	(14)
Physical condition	(14,46)
Skill at adjusting the load	(14)
Individual differences	(27,28)
4. Soldier variables, psychological	
Motivation	(24,45)
Attitude	(45,47)
Fear	
Fatigue	(32,45)
Comfort	(5,13)
Expectations	(44)

This list shows that portability is a situation-specific concept. Hicks and McCain (17), in writing about the optimal load, said, "Optimal as used here must be defined in relation to the capabilities of man and the requirements of the weapon system...(the) optimal load may vary from system to system."

Load Weight

There is nearly unanimous agreement among researchers that the weight of the load is the most important variable affecting portability. Winsmann and Goldman (52) have stated that "the results of...studies clearly support the concept that weight is the most important factor in load carriage." Even so, throughout history the weight of a soldier's combat load has usually exceeded the 45 pound maximum desirable load recommended by the British Royal Commission as long ago as 1867 (see the chart on page 25 of reference 22). Despite its age, that recommendation has been supported experimentally. Teeple and Bereschak (46) point out that "studies made in the attempt to find an optimum weight of load have yielded figures in the range of 30% to 40% of body weight." For the typical US Army soldier (51), these percentages are equivalent to about 45 to 60 pounds (22 to 28 kg).

Table 2 contains predictions of IMAAWS portability based on the allowable load, in terms of percentage of body weight, for the 5th, 50th, and 95th percentile soldier. The IMAAWS load weights are those supplied by the USAIS in their maxtrix of man-portability. The table shows that the 50th percentile soldier can carry the 63-pound total load (38 pounds of basic gear, plus 25 pounds of IMAAWS) only if the maximum allowable percentage of body weight is 45 percent. As we stated in the last paragraph, the range of percentages of body weight usually found to be optimal for loads is 30 to 40 percent. At those percentages, the 50th percentile soldier should not be able to carry any of the four load weights for more than a short distance. The Dragon weighs 25 pounds without its sight.

Portage Distance and Portage Speed

The distances specified in the matrix appear to be reasonable estimates of the distance requirements of a variety of combat tasks: assault, patrol, fall back to alternate position, and light infantry march. The portage speeds linked to these distances, however, are not so reasonable.

First, the term "dash" is too vague. We shall assign a value of 4 meters per second, which yields a completion time of 12.5 seconds for the 50-meter dash.

The other speeds yield elapsed times of 4.8 minutes for 400 meters, 1 hour for 3,500 meters, and 4 hours for 10,000 meters. These times seem to be too slow. The 10 km time, for instance, is roughly equivalent to a 1-1/2 foot step every 3/4 of a second. This pace is little more than a plod, even though FM 21-18 specifies this as the speed of cross-country movement. There may well be occasions in which 6 miles will have to be covered in less than 4 hours; if there are, the matrix will not have any validity.

TABLE 2

IMAAWS Portability as a Function of Allowed Percentage of Body Weight

Soldier Weight		Max. Allowable Load		Proposed IMAAWS Total Load (lbs.)			
%ile	lbs.	% body wgt.	lbs.	63	73	83	93
5	126.5	35%	44.3	XX	XX	XX	XX
		40%	50.6	XX	XX	XX	XX
		45%	56.9	XX	XX	XX	XX
50	156.6	35%	54.8	XX	XX	XX	XX
		40%	62.6	XX	XX	XX	XX
		45%	70.4		XX	XX	XX
95	201.9	35%	70.7		XX	XX	XX
		40%	80.8			XX	XX
		45%	90.9				XX

Note: "XX" indicates that the load cannot be carried.

Body Weight

Although researchers have long understood the importance of the porter's size in load-carrying (as evidenced by the common expression of optimum load weight in percent of body weight), no systematic effort has been made within the Army to match the strongest carriers with the heaviest loads. The selection of soldiers based on "the important criterion of physical strength or load-carrying ability is usually left until last (3)." For this reason, we question the presence of the variable, "personnel percentile," in the man-portability matrix. We hope that some effort will be made to keep the fifth percentile man from having to carry IMAAWS, particularly if the weapon system and the soldier's fighting load will weigh as much as 63 pounds (28.6 kg).

Engagement Condition

The inclusion of this variable in the matrix shows an awareness of the importance of the post-portage task. Throughout the literature, researchers have stressed the need to study the soldier's performance after carrying the load. The fact that they have had to continually emphasize the problem demonstrates that their warnings have largely been ignored. Carlock and Weasner (2) pointed out that "among the basic criteria of acceptance for any load-carrying are ease of portage and effect upon post-carrying combat skills." In another article (3), the same authors state that "the concept of portability implies not only the carrying of an item, but its successful employment at its destination." Torre (47) placed the problem in a tactical light: "From the infantryman's point of view, the foot soldier is constantly trading off the weight and bulk of the equipment he carries with the requirements of his mission."

The problem with merely specifying a recovery period, as the matrix does, is that we have no idea when we can state that recovery has occurred without knowing how much energy the subsequent task will require. There is some evidence [e.g., (28)] that gross motor activities are not greatly affected by portage. For instance, a heavy weapon system can still be assembled correctly after a long and difficult portage. On the other hand, finer psycho-motor tasks have been shown to be influenced by the stresses of portage, although Strauss and Carlock (45) admit that "recovery from whatever physiological impairment occurred during the load-carrying trials was extremely rapid."

Metabolic Cost

The majority of research on portability has dealt with the physiological effect of load carrying on the porter. Specifically, much has been written on the subject of the metabolic cost (or energy expenditure) of distinct portage tasks. Givoni and Goldman (11) and Pandolf, Givoni, and Goldman (33) have derived an equation for estimating the metabolic cost of portage given that certain variables are specified. This equation is:

$$M = 1.5W + 2.0(W+L)(L/W)^2 + E(W+L)(1.5V^2 + 0.35VG) \qquad (1)$$

where

M = metabolic cost (watts)

W = subject weight, nude (kg)

L = external load (kg)

E = terrain factor

V = velocity (m/sec)

G = grade or slope (%)

By making a few assumptions, we can calculate the metabolic costs in watts of each load weight, body weight, and speed combination in the matrix of man-portability. Before proceeding, however, we wish to emphasize, once again, that "clearly, the determination of maximum weights for portages of any distance cannot be made on the basis of energy expenditure alone" (45). Furthermore (3), "there is little relationship between energy expenditure and post-carrying performance on simple, combat-relevant tasks."

Having issued these warnings, we will specify the assumptions necessary for estimating the metabolic costs of portage. First, we have assumed subject weights of 57.4, 71.0, and 91.6 kg (51) to represent the 5th, 50th, and 95th percentile subjects shown in the man-portability matrix. The second assumption, based on the use of a cross-country rate (2.4 km/hr) under the 10 km condition in the matrix, was that the terrain to be traversed will consist of light brush (as opposed to roadways). Third, following Soule and Goldman (41), we will assume a terrain factor for light brush of 1.2. Last, we have assumed that the grade will be 0%. Of course, there will be important grade in almost any cross-country march, but since we have no way of predicting what those effects will be, we will use 0% to ease computation.

Equation 1 was not intended for estimates of the cost of short bursts of energy. Therefore, the metabolic costs of the dash condition should be regarded with caution. Remember that the energy costs would be lower if we chose a lower speed but the result could hardly be called a dash.

How many watts are too many? Hughes and Goldman (18) have proposed a value of 494 watts as the amount of energy an individual would willingly expend to perform "hard work." Higher levels of energy expenditure will generally occur only if forced by the situation. In the laboratory, this force could be a high treadmill speed. In the field, it could be the rigors of combat.

Several attempts have been made to give levels of energy expenditure that can be used in a practical way. Christensen (4) has developed the following definitions of different levels of work.

Unduly heavy work = over 872 watts

Very heavy work = 732 to 872 watts

Heavy work = 523 to 698 watts

Moderate work = 349 to 523 watts

Light work = 174 to 349 watts

Very light work = under 174 watts

Goldman (13) has also presented some guidelines for energy cost:

Comfort = 116 watts

Discomfort = over 349 watts

Exceeds voluntary hard work level = over 494 watts

Damage = over 1,047 watts

Exceeds maximum work capacity = over 1,186 watts

Goldman further expresses some tolerence limits related to duration:

Work endurance difficult beyond 15 minutes: 837 to 1,047 watts

Work endurance difficult beyond 1 hour: 698 watts

Work endurance difficult beyond 2-3 hours: 488 to 558 watts

Work endurance difficult beyond 8 hours: 349 to 419 watts

Table 3 contains the estimated metabolic costs of portage under the conditions which specify each cell. Examination of the table reveals the important effect of portage speed on energy expenditure as well as the lesser effects of subject and load weight.

Only the dash condition tallies energy costs well beyond the level of voluntary expense proposed by Hughes and Goldman. Table 3 indicates that all soldiers, regardless of their body weights, should be willing to carry any of the specified loads just as long as they do not need to maintain a portage speed greater than 1.39 m/sec.

The conclusion that all of the loads are portable, based on expected energy costs, is misleading. Notice that the main determinant of energy expenditure, according to Equation 1, is portage speed. Yet, virtually every study on load-carrying behavior asserts that load weight, not portage speed, is the most important factor in determining portability. Indeed, Hughes and Goldman (18) state that "speed is adjusted as a function of the load carried." McGinnis, Tambe, and Goldman (28) say that "weight (is) an important source of variance in load-carrying behavior which cannot be ignored and should not be underestimated." Since Equation 1 does underestimate the importance of load weight, while emphasizing portage speed, it is clear that energy expense is not the only, or even the most important, factor in determining the limits of portability.

TABLE 3

Estimated Metabolic Costs (In Watts) of Portage

Load Wgt (kg)	Subject Wgt (kg)	Per-centile	Portage Speed (m/sec) 4.0	1.39	0.97	0.67
	57.4	5	2606	427	274	198
28.6	71.0	50	3007	485	308	219
	91.6	95	3623	579	364	364
	57.4	5	2753	461	300	219
33.1	71.0	50	3150	514	328	236
	91.6	95	3761	604	381	271
	57.4	5	2907	499	329	245
37.7	71.0	50	3298	546	352	256
	91.6	95	3905	631	400	286
	57.4	5	3062	540	362	274
42.2	71.0	50	3447	580	378	278
	91.6	95	4048	660	421	302

The energy-cost approach to load-carrying behavior reveals another flaw concerning body weight. Equation 1 predicts that the 5th percentile soldier will expend less energy carrying a given load, no matter how heavy, than the 95th percentile soldier. We do not doubt that the smaller soldier expends less energy, but we have to point out that the increased strength of the larger soldier more than makes up for the increased energy cost. The result is that the larger soldier is the better porter.

The effects of terrain and grade on energy expenditure should not be forgotten. Both of these factors apply to the third term in Equation 1, that portion of the equation where the speed of portage enters into the calculation and where the greatest effect on overall energy cost takes place.

Let us consider the case of the 5th percentile soldier carrying the 37.7 kg load at 1.39 m/sec. When we assume a terrain factor of 1.2 and a grade of 0%, we estimate a metabolic cost of 499 watts which is close to the mean voluntary hard work rate that Hughes and Goldman (18) have proposed. Suppose we change the terrain factor to 1.5 (heavy brush) and add in a slight grade of 5%, the expected metabolic rate that results is 929 watts, much higher than the rate proposed by Hughes and Goldman. The difficulties in making *a priori* estimates of portability based on energy expenditure are apparent.

A final problem with the data resulting from Equation 1 is that those data are estimates of energy cost for a well-configured, back-packed load. The IMAAWS is not a well-configured load.

The matrix for man-portability cannot be filled in as requested, because too few of the variables affecting portage are included and because energy expenditure has been shown to be insufficient to predict portability. Successful predictions for portability must take into account more than just the weight of the load, the weight of the soldier, and the speed of portage. Portability cannot be evaluated independent of the task for which the particular material being carried will be used. Thus, a system which is portable for mechanized infantry may not be portable for light infantry.

SUMMARY

One of the objectives of this report was to fill in a yes-no matrix of man-portability provided to us by the USAIS. An attempt was made to accomplish this goal using data from a formula for estimating energy expenditure during portage. These data were shown to be insufficient predictors of portability because the formula emphasized portage speed at the expense of load weight. Load weight and load configuration are consistently agreed upon as the most important factors in load-carrying behavior. The formula, moreover, fails to account for the greater strength that heavier porters are likely to have; therefore, the ability of the heavier porter to withstand higher energy expenditures during portage is not predicted by the metabolic cost data.

The matrix of man-portability does not specify the tactical purposes for the IMAAWS. These uses have a great bearing on decisions about IMAAWS portability. Part I of this report pointed out that the IMAAWS is a squad weapon and must be carried over the same terrain and obstacles encountered by squad members carrying lighter or more portable loads. The current MAW, Dragon, is the least portable squad weapon primarily because of its configuration and method of carry. Both Dragon and IMAAWS (in its projected configuration) are long, thick tubes which must be carried by shoulder strap, a method of carry which is less efficient than strapping the weapon across a back pack.

The best example from the data on an upper limit of load weight for a soldier maneuvering in a field environment appears to be the load carried by the assistant M60 machine gunner in the IVCS study (34). His 90-pound load was well configured and balanced with most of the weight carried on the torso. He walked a 3,780 meter cross-country and road test course (in an unspecified time) and then negotiated the obstacle course, albeit with a greatly increased time compared to that of a rifleman. Maximum load weights for Dragon and IMAAWS gunners are much less because the weapons are not well-configured, balanced loads.

All of the studies which examined portability, through obstacle courses of MAW systems on the order of 30 pounds, plus a common load of about 40 pounds, show that the MAW gunner severely restricts the squad's maneuverability and reduces the pace at which the squad can move.

CONCLUSION

The data base reviewed in this investigation supports the previously stated USAHEL position that Dragon is at or near the weight limit of portability for the infantryman.

RECOMMENDATION

1. The IMAAWS gunner should be a dedicated gunner and should be so configured; for example, a pistol should be carried instead of a rifle.

2. IMAAWS should add less than 30 pounds to the load of the individual light infantry foot soldier.

3. If the weight of IMAAWS, including the night sight, exceeds 30 pounds, the weapon should be crew-served.

4. Consideration should be given to a heavier and, therefore, more effective IMAAWS for mechanized and motorized infantry because they would be required to carry IMAAWS only for relatively short distances.

5. Predictions of energy expenditure should not be used to evaluate portability.

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APPENDIX

IMAAWS PORTABILITY MATRIX

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TRUE COPY
DEPARTMENT OF THE ARMY
UNITED STATES ARMY INFANTRY SCHOOL
FORT BENNING, GEORGIA 31905

ATSH-CD-MS-F

SUBJECT: Manportability of the Infantry Manportable Antiarmor Assault Weapons System (IMAAWS)

Director
Human Engineering Laboratory
Aberdeen Proving Ground, Maryland 21005

1. References:

a. Message, USATRADOC, 051725Z Nov 80, subject: IMAAWS.

b. Confidential letter, ATCD-M-I, USATRADOC, subject: Letter of Agreement for the Infantry Manportable Antiarmor Assault Weapon System (IMAAWS), 14 March 1980.

c. Message, HQDA, DAMO-RQD, 191506Z Nov 80 (Inclosure 1).

2. The IMAAWS contracts which were awarded in September 1980 have been terminated. This action was taken as a result of DA guidance which is summarized in reference a. One of the primary reasons for contract termination was that it was doubtful that a rifle squad could carry a 55 pound IMAAWS very far (the upper limit allowed by reference b). DA has directed TRADOC to reexamine the IMAAWS requirements, with particular emphasis on weight, reference c. The Infantry Close Combat Antiarmor Requirement Study (ICCAARS) should provide most of the answers needed; however, manportability aspects will not be addressed.

3. Request your recommendations pertaining to the manportability issues at Inclosure 2 by 20 February 1981.

4. USAIS Point of Contact is MAJ John Adams, AV 835-1016/5314.

FOR THE COMMANDANT:

2 Incl
as

S/GUS H. WATT
T/GUS H. WATT
Colonel, Infantry
Director, Combat Developments

CF:
Cdr, TRADOC, ATTN: ATCD-M-I

Incloeure 1 not included in report.

Message not legible.

IMAAWS MANPORTABILITY

1. DEFINITION: One man carrying the complete system necessary to acquire and engage a target over distances and rates of movement required.

2. IMAAWS system characteristics (affecting 1 manportability) are expected to be as follows:

a.	Weight (tracker/acquisition device)	4 to 10 pounds
	(round)	21 to 35 pounds
b.	Carry Length	40 to 48 inches
c.	Diameter (launch tube)	4 to 7 inches
	(end caps)	6 to 12 inches

d. Will be carried by handle or strap, in one or two parts.

e. May be shoulder fired, bipod supported, or ground launched (like MILAN).

f. Must be capable of rapid movement up-stairs for military operations in urbanized terrain.

g. IMAAWS weights must consider the 38 pound "fighting load" carried by each Infantryman.

3. OPERATIONAL SCENARIO: The IMAAWS (complete system) must be capable of being carried by only 1 man for up to 10km at rates varying from "dash" (for 50 meters or less) to 2.4km/hr (for 10km) cross-country. The person carrying IMAAWS must retain operational effectiveness throughout the mission (which is defined as the capability to effectively deploy and utilize the system at various times after completion of the movement).

4. ISSUES:

a. Can the 5th, 50th and 95th percentile Infantryman, carrying the IMAAWS (and "fighting load") effectively employ the system after meeting the conditions prescribed at Inclosure 1? If any responses are "no," how much should the IMAAWS weigh to meet these conditions?

b. What should be the maximum carry length and launch tube/end cap diameter?

SUITABILITY FOR 1 MANPORTABILITY

(meters) DISTANCE	TOTAL LOAD (POUNDS)[a] 63			73			83			93			ENGAGE CONDITIONS	(Km/Hr) RATE
50													IMMEDIATE	DASH
													5 MINUTES	
400													IMMEDIATE	5
													5 MINUTES	
3500													IMMEDIATE	3.5
													15 MINUTES	
10,000													IMMEDIATE	2.4
													15 MINUTES	
PERSONNEL PERCENTILE	5	50	95	5	50	95	5	50	95	5	50	95		

[a]INCLUDES 38 POUND FIGHTING LOAD (ALL CONDITIONS)

CONCURRENCE WITH COMMENT

Change Inclosure 2, paragraph 3, from "unimproved roads or trails" to "cross-country." IAW FM 21-18 a rate of 2.4 KMPH is specified for cross-country movement.

JERRY C. SCOTT
Colonel, Infantry
Director